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PROCEEDINGS OF THE WORKSHOP ON AQUATIC WEEDS: CONTROL AND ITS ENVIRONMENTAL CONSEQUENCES

Environmental Protection Agency
Environmental Research Laboratory
Gulf Breeze, Florida
February 25-26, 1980

Edited by
Gerald E. Walsh
Environmental Research Laboratory
Gulf Breeze, Florida 32561

ENVIRONMENTAL RESEARCH LABORATORY
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U.S. ENVIRONMENTAL PROTECTION AGNECY
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FOREWORD

The Environmental Protection Agency has been authorized by Congress to conduct a research program to develop environmentally acceptable methods for control of aquatic weeds. Methods are needed that will control weeds safely, economically, and effectively without harm to (a) sportfishing or other water recreation, (b) irrigation canals, reservoirs, lakes, and ditchbacks, (c) recreation areas, and (d) aesthetics.

Experts in chemical, biological, mechanical, and integrated methods of weed control attended the "Workshop on Aquatic Weeds: Control and Its Environmental Consequences" at the Environmental Research Laboratory, Gulf Breeze to discuss problems associated with water quality and to advise EPA with regard to efficiency and effects of control technology. Proceedings of the workshop summarize control technologies currently used and in development. They are designed to aid aquatic weed control program managers in EPA's Agriculture and Non-Point Source Management Division of the Office of Environmental Processes and Effects Research.

Henry F. Enos
Director
Environmental Research Laboratory
Gulf Breeze, Florida

ABSTRACT

The "Workshop on Aquatic Weeds: Control and Its Environmental Consequences" reviews the state-of-the-art of the chemical, biological, mechanical, and integrated control of aquatic weeds. Participants discuss problems in the field of aquatic weed control and how EPA can assist in working toward their solutions.

Chemical control is the most common method used for aquatic weeds. Need for information is cited in five areas of chemical control: an inventory of weed problems in the U.S.; basic data on biology of aquatic weeds; concentrations of herbicides required for maintenance of acceptable weed biomass; the effectiveness and safety of 4,4-D; and the controlled-release formulation for long-term control of weeds. Methods are needed to: integrate use of conventional and controlled-release formulations; measure concentrations of herbicides in plants (including irrigated crops), animals, silt, and detritus during long-term treatment; determine chronic effects of herbicides on non-target organisms; and utilize naturally occuring herbicides.

Biological weed control by man attempts to use natural predators for control of weed biomass, but intentional biological alteration of aquatic systems involves the risk of undesireable permanent consequences. Research needs are defined in these areas: comparative studies between lakes with and without weed infestations to learn natural mechanisms of control; plant pathogens effective for weed control; a battery of species-specific pathogen types; and investigation of the relation of environmental stresses to susceptibility of pathogens; and the basic biology and methods for production of the sterile hybird grass carp.

Mechanical control of aquatic weeds involves the collection of plants with subsequent treatment and return to the water, or removal from the infested water body. The cost of harvesting and disposal of weeds is often prohibitive, but the mechanical methods allow rapid removal of plants when necessary.

Integrated control of aquatic plants utilizes methods of chemical, biological, and mechanical control concurrently or sequentially in a systematic program for initial biomass reduction and long-term maintenance. Development of integrated methods relies heavily upon development of other methods, which have advanced sporadically and asynchronously. The following integrated methods are viewed as the most likely to be effective: herbicidal treatment followed by stocking with fish; herbicidal treatment followed by application of pathogens; mechanical harvesting followed by stocking with fish; mechanical harvesting followed by application of pathogens; treatment with insects, followed by application of pathogens; and introduction of competitive plants.

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INTRODUCTION

The purpose of the "Workshop on Aquatic Weeds: Control and its Environmental Consequences" was to bring together experts in the field of aquatic weed control for informal discussion of current problems and how the U.S. Environmental Protection Agency can assist in their solution. It was recognized that the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, the Tennessee Valley Authority, and the U.S. Department of the Interior have programs in aquatic weed control, and it would be best if EPA develops a program that emphasizes methods of control and their environmental consequences. However, there will be some areas of research that are of interest to all of these Federal agencies, and cooperation, expressed as joint funding of projects in these areas, should be encouraged on a national basis.

Aquatic weeds are threats to many areas of the country. Two species are of special importance, hydrilla (Hydrilla verticillata) in the southern United States, and eurasian watermilfoil (Myriophyllum spicatum) in the northern United States, but pondweeds (Potamogeton spp.) and filamentous bluegreen algae are also widespread pests. Brazilian elodea (Egeria densa) is also a problem in some locations. Although effective herbicides are available, it is often difficult to control hydrilla, watermilfoil, pondweed, and brazilian elodea with herbicides or plant growth inhibitors, not only because they are submersed and, therefore, hard to reach with conventional methods of chemical treatment, but also because public perception of possible adverse effects often precludes herbicidal treatment.

Filamentous algae may be controlled with substances that contain copper, but this metal may be a pollutant in some situations.

At present, chemical means of control, in general, are the simplest and least expensive methods of aquatic weed control. They do, however, sometimes have undesirable effects, such as lack of target-plant specificity, toxicity to animals, and persistence of residues.

For these reasons, it would be best for EPA to concentrate its research efforts on development and testing of biological, mechanical, and integrated controls. Emphasis should be placed on biological and integrated (chemical, biological, mechanical) methods. Chemical control should be addressed as part of an integrated scheme, with a view toward use of less chemical for weed control. In either case, immediate results should not be expected because a large amount of methods development is needed in the biological area, and some methods are not developed to the point that they can be meshed with others in integrated programs. Also, because of differences in weed species and in water bodies, methods must be adapted to local conditions.

A condensation of the salient points of the workshop in the areas of chemical, biological, mechanical, and integrated control of aquatic weeds follows. An overview and preliminary remarks by group leaders precede an outline of important points and recommendations by the participants. Since

these recommendations will be used for evaluation of grant requests, this method of reporting was adopted to provide a succinct overview of weed research in relation to EPA needs for review of research proposals.

CHEMICAL CONTROL

Aquatic plants may be killed, controlled, and maintained at acceptable population densities by herbicides and plant growth inhibitors. Management of aquatic plant biomass by synthetic chemicals is, in general, the easiest and least expensive method available, but it may have undesirable effects, such as lack of target plant specificity, toxicity to non-target organisms, and persistence of residues. Steward (1979) listed chemicals historically used for control of aquatic weeds:

Floating weeds: amitrol T, diquat, silvex, 2,4-D;
Emersed broadleaf weeds: amitrol, amitrol T, silvex, 2,4-D glyphosate, dalapon:
Submersed weeds and algae: organic copper, copper sulfate, copper carbonate, diquat, silvex, 2,4-D, dichlobenil, fenac, simazine, endothall;
Irrigation and drainage ditch banks: amitrol T, 2,4-D, dalapon, dicamba, dinoseb, duiron, hexazinone, krenite, TCA; and
Irrigation and drainage canals: copper, diquat, duiron, endothall, acrolein, aromatic solvent.

Only a few of these materials are registered for use in aquatic systems, but the methods by which registered chemicals are applied to weeds are important with regard to extent of control and effects upon non-target species. Herbicides and growth regulators are often formulated with polymers to control drift, on granules of various compositions, in oil droplets, or with synthetic plastics, elastomers, waxes, or naturally-occurring polymers that control drift or release of the chemicals (Steward, 1979; Harris 1979).

Herbicides and plant growth regulators are relatively non-persistent in natural environments. They cause changes in aquatic ecosystems, however, and their impacts must be judged in relation to (1) toxicity to the target species, (2) relative toxicity to non-target species, (3) fate of residues and their significance to water, fishes, crops, livestock, and foods, (4) conditions that affect toxicity, efficacy, and persistence, and (5) synergizing or antagonizing activity of carriers, formulations, metabolites, degradation products, or other pesticides (Gangstad 1978).

The consensus of the meeting was that, in spite of problems associated with the five points listed above, chemical control, when used correctly, is environmentally safe and should be continued in the future. Most discussion was devoted to experiences of the discussants with regard to efficacy and correct usage -- correct usage as it relates to goals of control and maintenance programs -- development of new herbicides and formulations, and use of chemicals in different types of water and geographical areas.

Statement of the Chemical Control Group Leader

Chemical control is the dominant method used for aquatic weeds today. We should discuss this method from the standpoints of efficacy, environmental effects, and environmental compatibility of currently registered compounds, and should consider recently-developed controlled-release methods, growth regulators, abcissic acid, allelopathic compounds, and other natural growth regulators. We should consider mainly the three aquatic weed species that are controlled primarily by chemicals, i.e., hydrilla, eurasian watermilfoil, and waterhyacinth. Also, filamentous algae must be considered as dominant aquatic weeds because algicides are used in great quantities in western irrigation systems.

General Discussion

1. Inventory of weed problems. A nationwide inventory of aquatic weed problems is needed. Although this is not specifically a chemical control problem, it is very important to control programs: chemical companies need to know the extent of weed problems in order to plan developmental research; managers of aquatic resources need to know the identity and distribution of aquatic weed species. The inventory should relate to user-group perceptions, which are very important with regard to weed control. For example, irrigation system managers desire weed-free water whereas fisherman may desire a margin of aquatic plants around the perimeter of the lake.

2. Lack of basic data on aquatic weeds. Relatively little is known about the basic biology of aquatic weeds. It is not known why a species may be a pest in one lake, but occur at reasonable densities in a nearby lake. For example, hydrilla may be a pest in a lake for one year, but not in the next year, after which, it may become a pest again. A species may be abundant in one portion of a lake, but not in another. If we knew why these phenomena occur, safe methods for control might be devised. Herbicides used to control aquatic plants are not developed in relation to any physiological characteristics of those plants. In fact, often, they were developed for use on terrestrial plants and later found to be effective against aquatic weeds. We are trying to control target species without knowing fully their physiological characteristics or how they differ from non-target species. Research is needed on the basic biology of major aquatic weed species.

3. Maintenance level for aquatic weeds. In many areas of Florida, waterhyacinth is no longer a problem because of effective maintenance programs. Acceptable maintenance levels should be achieved for other plants. This is, however, especially difficult for submersed plants, and different treatment will be required for different water bodies in relation to weed species and individual characteristics of those bodies. Just as important is the level of control as related to effects on the whole system and what degree of control is acceptable in relation to use.

4. Effectiveness of 2,4-D for maintenance control of water hyacinth in Florida. After lengthy discussion, it was agreed that 2,4-D is an effective and environmentally safe chemical for control of water hyacinth and that insects and pathogens probably aid in control. Diquat is now being used in South Florida, and the general consensus was that it is not as efficient or environmentally safe as 2,4-D. Diquat kills many non-target plants, such as bullrushes, but because the public perceives 2,4-D as a dangerous chemical, although it is not, diquat is used instead. Public perception of effects of chemical spraying is not always correct and should not be the guiding principle for weed control by chemicals.

5. Controlled release formulations. New formulations of herbicides, particularly controlled-release formulations that allow low concentrations of herbicides to be effective, have been developed. These are particularly effective in preventing regrowth after application to hydrosoil when it is exposed to air during drawdowns or periods of low flow. It is estimated that these formulations will be effective for at least a complete growing season or a full year. As yet, there are not enough data to determine effects of long-term exposure of non-target organisms to the lowest concentration of 2,4-D that inhibits growth. Also, research is needed on effects of water chemistry and water temperature on persistence and effectiveness of herbicides used in controlled-release formulations.

Recommendations

1. Develop methods that use conventional herbicides to reduce plant biomass, with subsequent maintenance by controlled-release herbicides to prevent regrowth.

2. Develop research methods for determination of dissipation, metabolism, and physical breakdown of chemicals in static and flowing-water sites. The latter use-pattern is of primary importance to aquatic vegetation control and management in western states where irrigation systems are severely disrupted by aquatic weeds. The goal of this research is to help establish the appropriate application and water management techniques that will minimize or eliminate exposure of man, livestock, and non-target aquatic plants and fishes to toxic chemicals.

3. Determine herbicide concentrations in target aquatic plants as a means of addressing potential impact of ingestion of target vegetation by non-target vertebrate and invertebrate grazers. This is a neglected area of research that may have benefits beyond the evaluation of impact on non-target species. Information on efficiency of herbicide uptake and retention in target plants may point to more selective application techniques via placement and formulations of herbicides.

4. Determine the retention of trace amounts of aquatic herbicides in representative crops normally grown in areas where irrigation is dependent upon conveyance systems in which aquatic herbicides may be used. This information is essential for evaluation of impacts on crops, and is a prerequisite for establishment of commodity tolerances by EPA.

5. Determine the significance of nutrient release from decomposing target aquatic plants. Under what conditions might one expect algal blooms that result from nutrient release to be more detrimental than existing macrophyte populations?

6. Determine the long-term effects of controlled-release formulations. These are likely to be chronic, sub-lethal concentrations that may affect microflora, and benthos. What potential is there for direct ingestion of controlled-release formulation pellets by animals?

7. Determine the potential hazard of water-borne, herbicide-laden silt and detritus.

8. Support research on potential use of naturally-occurring substances that have herbicidal qualities. These may be present on soil or water or may be extracted from species that use extracellular toxic substances to survive competition with other species. Determine specificity, persistence, and toxicity of allelopathogens and other natural substances.

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BIOLOGICAL CONTROL

Structure and dynamics in natural communitites are regulated by complex biological phenomena, one of which is the effect of predatory species on population density of prey species. An important part of such population density control is the dampening of plant biomass by herbivores (e.g. biomass of phytoplankton as a function of grazing rates by herbivorous zooplankton, Shoemaker 1977). Overproduction by primary producers in a system is compensated for through comsumption by herbivores, whose numbers and biomass are controlled, at least in part, by prey numbers and biomass. The result of such a cybernetic system is maintenance of constancy of biomass for a period of time (Margalef 1968).

Biological weed control by man attempts to use natural predators to control biomass of weed species. From theory expressed in the previous paragraph, it is clear that a reproducing population of plant predators will not eradicate weeds, but that numbers of prey and predator will oscillate (Hutchinson 1975), both existing at concentrations acceptable to man.

So far, application of biological controls to weed problems has met with moderate success. For example, the alligatorweed flea beetle (Agasicles hygrophila) has controlled alligatorweed (Alternathera philoxeroides) well in Louisiana, but not in Alabama (USDA 1977). A large amount of work is continuing on fishes (Guillory 1979), insects (Buckingham et al. 1979), and plant pathogens (Conway et al. 1979), but biological control remains only a potential tool for large-scale control of aquatic weeds.

Statement of the Biological Control Group Leader

Researchers in biological control of aquatic plants have a tremendous responsibility to environmental protection because of the complexity of aquatic ecosystems. Any intentional alteration of these systems involves the risk of undesirable consequences. The risk is compounded when the modification is irreversible, as is typically the case in introduction of nonnative species that subsequently reproduce. Nevertheless, potential benefits from introduction of organisms for control of nuisance aquatic plants can outweigh the risks if strict guidelines are followed. Suggested guidelines include (1) the need for an introduction must be clearly established, (2) the organism must have a desirable ecological and economic impact, (3) the species must have minimal niche overlap with native species, (4) it should cause minimal reduction of non-target species, (5) field releases should be studied and ecological impact determined, (6) disease interrelationships should be carefully examined, and (7) methods for control of the introduced species should be established prior to large scale introduction.

General Discussion

Use of Insects

1. Host specificity. There is a large gap in our knowledge of host specificity with regard to insects and aquatic plants. One researcher felt intuitively that aquatic insects often do not attack specific host species, as do terrestrial insects, but tend to attack certain types of plants or species groups. It would be difficult, if not impossible, to test an insect against all plants that may be exposed to it. Also, an insect may feed on many plant species in the laboratory, yet be found on only one or two species in the field.

2. Cost. The cost of introducing insects is very high: finding suitable species, quarantine, and testing can take 8 to 10 years and cost several million dollars.

3. Potential for altering ecosystems. A very important consideration is the potential an insect has for altering an aquatic ecosystem. Besides killing the weeds, an insect could alter an ecosystem in an acceptable way if it did not affect a favored plant species, thus making moot the problem of host specificity. As a point in proof that host specificity is not necessary, it was mentioned that fishes often do not feed selectively, yet there is no requirement for specific food selection by them.

Use of Plant Pathogens

1. Lack of information on aquatic plant pathogens. Most work on plant pathogens, such as fungi, has been done on terrestrial species. Little is known with regard to methods for isloation, maintenance, and testing of aquatic pathogens. Aquatic pathogens are very specialized: they are often obligate parasites that cannot now be cultured. We need to learn how to culture them and how to expose submersed weeds to them. Many pathogenic species occur in soil and water, attacking plants in both systems. We do not know if it is safe to use them for aquatic weed control.

Genetic manipulation may be an important tool in development of plant pathogens. However, most mutations result in loss of pathogenicity, rather than enhanced pathogenicity.

2. Cost of producing pathogens. Once a pathogen is isolated and proven to be useful for weed control, cost of mass culturing and production of inocula will be relatively inexpensive, except for obligate parasites.

3. Necessity of repeated treatments with pathogens. Since numbers of pathogenic organisms will decline as plant numbers decline, it may be necessary periodically to reinstigate epidemics.

Use of Fishes

1. Grass carp. The major comments with regard to use of the grass carp (Ctenopharyngodon idella) were reservations on its ability to control

vegetation and on possible adverse environmental effects. Although grass carp have controlled weeds in some areas, they have not done so in others. They are also known to have caused changes in water quality; some people fear that the carp may reduce stocks of sport fishes, such as bass and bluegill; and control, when it occurs, is slow compared to chemicals methods. However, once control is established with fish, it lasts for a relatively long period of time.

2. Hybrid carp. The hybrid carp, a cross between the female grass carp (C. idella) and the male bighead carp (Hypophthalmichthyes nobilis), has been proposed for introduction for weed control. It is now being tested in several laboratories and in field situations. One researcher said it has "the greatest potential as an environmentally acceptable plant control method that I have ever encountered." An important advantage of the hybrid over the grass carp is that the hybrid may consume both vascular plants and filamentous algae, whereas the grass carp primarily eats vascular plants.

Testing of the hybrid carp for weed control has begun recently in the United States, and its use, singly and in combination with other control methods, needs to be investigated.

There is only one breeder of hybrid carp in the United States, and it was stated that research is needed on technology to produce the fish.

Recommendations

1. Comparative studies should be made between lakes where a weed species is a problem and lakes where it is not a problem. For example, in Lake Jackson (Florida), hydrilla seems to be under natural controls. The reasons for such control in this and other lakes may or may not be biological, but they should be studied.

2. The search for aquatic plant pathogens should continue. Methods for isolation and maintenance of pathogens should be developed. A battery of pathogen types should be developed for use on each weed species that has resistant strains. Endemic species of pathogens should be used whenever possible.

3. Research should be done on the relation of environmental stresses to susceptibility of host plants to pathogens.

4. EPA should fund research in technology development for production of hybrid carp.

5. The basic biology of the hybrid carp should be studied, i.e., food preferences of age classes, growth rates, etc. in the field and laboratory.

6. Effects of hybird carp on total ecosystems should be studied.

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MECHANICAL CONTROL AND HABITAT MANIPULATION

Mechanical control of aquatic weeds involves collection of plants with subsequent treatment and return to the water, or removal from the infested water body (harvest method). The former may be appropriate for eutrophic systems, but the harvest method is used most often. Ordinarily, plants are harvested by a mechanical device and transported to the shore, where other mechanical devices collect the harvest and either deposit it there or transport it elsewhere for disposal or use.

The types of machinery used for harvesting aquatic weeds have been described by Livermore and Wunderlich (1969) and Nichols (1974). Choice of such equipment as harvesters, transporters, and weed ploughs depends upon: (1) the type of plant to be harvested, (2) the type of water body, (3) the debris or other foreign matter encountered, (4) the nature of the shoreline, (5) the prevailing weather conditions, (6) the harvesting concept utilized, and (7) the plant disposal system contemplated (Gangstad 1978). Also of importance with regard to the objectives of management plans are: (1) cost, (2) results, and (3) ecological implications (Nichols 1974).

There are two main concerns with regard to mechanical controls: (1) cost including energy consumption, and (2) disposal of harvested weeds. The cost of harvesting and disposal of weeds is often prohibitive, especially when harvesting must be done on a large scale. Often, as with waterhyacinth, weeds grow almost as fast as they are harvested, so that harvesting must begin again shortly after an area is cleared.

Water constitutes approximately 90% of the weight of aquatic weeds, and when harvested, a relatively large amount of water may be removed from a heavily infested system. Also, the heavy weight and large volume of the weeds make them difficult to transport from their point of origin. Nevertheless, research is being done to make aquatic weeds useful, and if it is successful, harvesting may become an economically feasible method of aquatic weed control. One example of a scheme (Fig. 1) to utilize the plants was given by Koegel et al. (1972). Little (1968) suggested that aquatic plants could be used as human and animal food, for composting, and for fiber production.

There are no mechanical harvesters available for freshwater algae, nor are there any processes available for making these algae useful economically.

Habitat manipulation for control of aquatic weeds includes such procedures as: water level manipulation, dredging, artifical shading, nutrient limitation and inactivations, and gravel, sand, and other types of blanketing. Habitat manipulation limits growth by alteration of one or more physical or chemical factors required by plants. Two methods were discussed at the meeting as immediately feasible: water level manipulation, and use of fiberglass screens as blankets on the hydrosoil.

Introductory Remarks by the Mechanical Control Group Leader

I would like to begin this session with a brief overview of the history

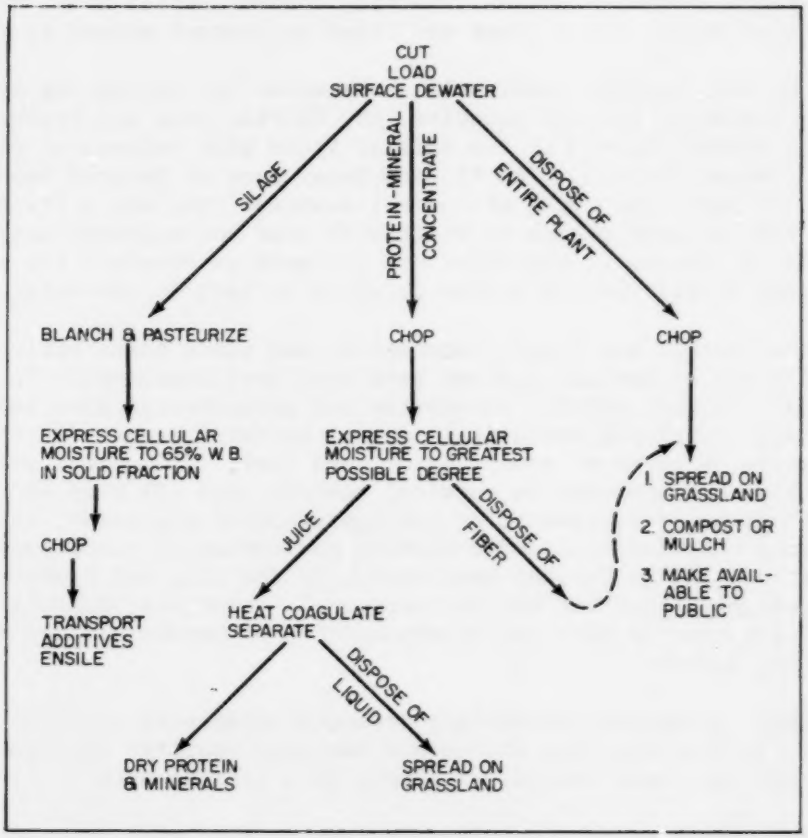

Fig. 1. Pathways for processing harvested aquatic vegetation (Koegel et al. 1972).

of weed control by mechanical means. Mechanical control was the first control method used for waterhyacinths in Florida and Louisiana around the turn of the century. During the first 50 years or so of this century, several chemicals were tried or actually used operationally with varying degrees of success. Some were toxic to man and non-target organisms, whereas others were not effective or were to expensive. Since chemicals did not afford adequate control, hyacinth control, until 1950, was mainly by mechanical means, i.e., booms and traps to prevent spread by drifting.

Since 1948, various combinations of mechanical harvesting systems have been tested by several agencies, the Florida Game and Freshwater Fish Commission conducting most of the initial tests with mechanical methods for control of waterhyacinth. The Florida Department of Natural Resources designed and built two types of control devices: one was a fixed-point take out that allowed plants to drift with wind and currents until they were piled on the shore; the other was designed to macerate the plants and pump the slurry through a pipe to shore or back in the water.

Neither method was highly successful, and since these early beginnings, very few mechanical systems have been used continually in the state of Florida. Neither private enterprise nor governmental agencies have substantially developed mechanical control systems because (1) they are too expensive in terms of money, labor, and fuel, (2) control over a large area is slow when compared to chemical control, and (3) they are inflexible, i.e., each piece of equipment, or configuration of equipment, is designed to work at a specific site under certain environmental conditions. Mechanical control is further complicated by the size and cumbersomeness of the equipment, need for trained personnel, easements, disposal areas, support logistics for fuel and transportation of personnel, and many other complicating factors.

Overall, mechanical harvesting presents managerial problems that chemical spraying does not, but the method has some positive attributes, particularly the rapid removal of plants in a limited area:

- When harvested, a plant is gone immediately; when sprayed with a herbicide or treated with a pathogen or insect, it may persist in a decomposing state for some time.
- No potentially harmful materials, except for small amounts of oil or hydraulic fluid, are added to the water during harvesting, and the method is generally considered to be environmentally acceptable.
- In some instances, nutrient removal by removal of plants is beneficial to the aquatic system.
- Although as yet unproven, it is possible that mechanical removal of some aquatic weed species allows for recolonization by less pestiferous species.

There is a need to investigate alternative means of mechanical control in order to offset adverse effects of herbidices and to be ready if use of

effective herbicides in aquatic systems is denied in the future. In 1975, the U.S. Army Corps of Engineers, Jacksonville District, began a program that had two goals: to evaluate currently available equipment, and to encourage design and development of new equipment whose use would be more economically feasible than that available now.

Between 1976 and 1978, tests were conducted on currently available equipment on the St. John's River (waterhyacinths), Orange Lake (hydrilla), and Withlacoochee River (waterhyacinth and hydrilla). The tests were made with the Aquamarine Systems "Aqua Trio", which consists of three pieces of equipment: a harvester, a transporter that conveys the harvest to the shore, and a shore conveyor that loads plants on trucks for disposal. The system was successful in Orange Lake in 1977, and was competitive with chemical means with regard to control. Approximately 160 acres of hydrilla were cut and harvested at a cost of approximately $454 per acre for the entire growing season.

Only one potentially acceptable mechanical system has been designated since 1976. The machine was manufactured by Limnos, Ltd., Canada, and tested against hydrilla on the Withlacoochee River in 1979. Although evaluation of the system has not been completed, several aspects are encouraging, particularly the speed of cutting. It should be operational in 1980.

The U.S. Army Corps of Engineers, Waterways Experimental Station, continues to encourage design of new harvesting systems and ecosystem simulation models that could aid in their design. Through use of a terrain analysis computer system, it was estimated that approximately 75 per cent of hyacinths in the St. John's River are unreachable by conventional harvesting equipment. Simulation models will aid in determining how to remove the plants, where to deposit them, and how long it will take for them to deteriorate.

General Discussion

1. Effects of mechanical control on dispersal of weeds. Eurasian watermilfoil and hydrilla propagate by fragmentation; i.e., pieces break from the stock and may develop into complete plants. Any two-stage operation of cutting and collection is bound to cause fragmentation, a highly significant means of dispersal for eurasian watermilfoil and hydrilla. Thus, cutting and collection may compound problems with these weeds. However, in a single-step operation of collection only, dispersal by fragmentation may not be significant.

2. Time of harvesting. The time of year in which weeds are harvested may be important. There is evidence that it is best to cut and harvest some weeds in the fall for long-term control. However, research in this area in needed for the major weed species.

3. Concepts of "aquatic plant control" and "aquatic plant management." It was suggested that aquatic weeds need not simply to be controlled, but

that the problem should be approached in a broad management scheme. This scheme would include harvesting, disposal, commercial use of harvest, and multiple harvests to control buildup of nutrients in some lakes.

4. Disposal of harvested weeds. The cost of weed disposal is often great, and makes mechanical harvesting economically uncompetitive with chemical control. However, in some cases, the harvest may be disposed of in the lake or reservoir itself and this would decrease cost. Actually, when herbicides are used, the plants decompose in the water. Harvest may be returned to the general water mass after shredding or it may be baled and deposited on the shore. Research is needed on effects of both types of disposal. One experiment has been tried in Orange Lake in Florida: baled material placed in shallow water near the shore decayed quickly without apparent detrimental effects. It would be well to know how to bale weeds so that they sink to the bottom and decay there.

One member felt intuitively that return of weeds was ecologically unacceptable, and the group agreed that studies should be done on effects of harvested weeds returned to water.

5. Harvesting of weeds as a method for removal of nutrients from aquatic systems. Removal of weeds may be an effective method for removal of nutrients in some lakes. Four or five harvests may cause significant decrease in nutrients in an oligotrophic lake, whereas it may have little or no effect in eutrophic systems or where waters contain naturally high concentrations of nutrients.

6. Utilization of harvested weeds. If aquatic weeds are to be utilized economically, there is a need for development of commercial products. These products will have to utilize the plant material after the water is removed (aquatic plants are at least 90% water, by weight). Fresh aquatic plants are very heavy, and the cost of hauling harvest overland to a processing plant is great. An analogy has been drawn between catfish farming and weed harvesting. However, catfish are raised in special ponds. Profit from any commercial product will not lower the cost of machanical field operations and hauling, so the total cost of harvesting, hauling, and preparation of product have to be considered.

Recommendations

Several mechanical devices are used for weed control. The following is a list of them and what research needs to be done.

Type of Control	Used Currently	Needs additional Testing
Harvester	Aqua-marine [1/], [2/]; Aqua Trio; Altostar System[1/], [2/]	Limnos Limited System[1/], [2/]
Dredging	-	Water-Vac System[1/], [2/]
Bottom screening	Fiberglass[2/] screens	Vacume maintenance of screens[1/]
Rotovating	Rotovators on[1/], [2/] tractors & boats	-

[1/] Research is needed on the environmental effects of water disposal of plant material when using this method.

[2/] Research is needed with regard to ecological impacts of this method. Impacts include effects on nutrient cycling, food chain dynamics, bottom stabilization, and water quality characteristics.

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INTEGRATED CONTROL

Integrated control of aquatic plants utilizes methods of chemical, biological, and mechanical control concurrently or sequentially in a systematic program for initial biomass reduction and long-term maintenance. It has two purposes: effective control, and minimal environmental impact by reduction of unwanted effects of any single method. The latter is achieved through synergistic interactions of methods applied at rates below those when each is used singly. For example, there is evidence that herbicidal treatment for biomass reduction of hydrilla, followed by introduction of grass carp for maintenance, will reduce the need for repeated herbicidal treatment and have little or no effect on sport fishes.

Relatively little work is being done on development of methods for integrated control of aquatic weeds. Such development relies heavily upon development of other methods, but these have advanced sporadically and asynchronously. Methods for use of insects and plant pathogens in integrated systems will probably take the longest time to develop, whereas integration of chemical, mechanical, and fishes offers the best opportunity for short-term development.

Statement of the Integrated Control Group Leader

The integrated control method involves use and coordination of several methods (chemical, mechanical, biological) to achieve desired vegetation densities within aquatic systems. By integrating several control methods, the most desirable aspects of each method can be utilized. For example, chemical and mechanical methods remove vegetation rapidly, whereas biological organisms remove weeds more slowly, are longer lasting, and less costly. The advantage of integrating methods is that vegetation can be managed more precisely than when a single method is used. After initial control is achieved, biological organisms can be stocked in fewer numbers in order to maintain vegetation at the desired density, and the extent of treatment with other methods may be decreased. Biological control with grass carp alone is promising, but this fish can completely remove all vegetation from the system and eventually affect emergent plants that are important for wildlife and fishery benefits. If stocking rates are decreased and only regrowth is removed after prior treatment, this problem will be eliminated.

General Discussion

1. Integrated control programs and the U.S. Army Corps of Engineers. The U.S. Army Corps of Engineers does not have major operational programs in integrated control. It considered using chemical, biological, and mechanical methods, together or sequentially, but found their developments were not synchronized. It will be at least two years before the Corps is ready to begin major research efforts in integrated control.

2. Herbicide treatment, followed by stocking with fish. Two projects are being done on reduction of plant biomass with contact herbicides and subsequent control by grass carp or hybrid carp, but more work is needed in this area. The U.S. Army Corps of Engineers is also doing studies on effects of herbicide residues on stocked fish. For example, fish that are stocked after treatment with Komeen are being examined for effects of copper on survival and behavior.

3. Herbicide treatment, followed by application of pathogens. It is a distinct possibility that stress of plants by herbicides, followed by treatment with pathogens will allow proliferation of the pathogen. The herbicide may cause physiological changes in the plant that allow the pathogens to cause disease. Application of a slow-release herbicide followed by the pathogen should be investigated. Essentially, this approach is an attempt to induce an epidemic.

4. Mechanical harvesting, followed by stocking with fish. Mechanical harvesting is a good method for rapid removal of weeds. If followed immediately by stocking with fish, desired biomass of plants might be maintained. Methods for this approach should be developed.

5. Mechanical harvesting, destruction or both, followed by application of pathogens. Harvesting or mechanical injury to weeds may cause them to be more susceptible to plant pathogens, but this needs to be investigated.

6. Treatment with insects, followed by application of pathogens. Insects that feed upon, or lay their eggs in, aquatic plants may cause lesions that allow entrance of pathogens. Effects of insects should be studied to learn if insect-caused lesions aid establishment of plant diseases.

7. Competitive plants. Theoretically, once weed biomass is reduced by mechanical or chemical means, desirable plants that compete with them could be planted and subsequent growth of the desired plants and suppression of growth of weeds would occur. Little is know of this potentially useful integrated method. Developmental studies should be started.

Recommendations

Recommendations for use of two-method systems are given under "General Discussion" and outlined in Table 1. However, integrated control eventually will use combinations of the other three types of control. Table 2 gives combinations of methods that can be used in the near future. They are ranked in relative order of how rapidly they can be developed, their importance to regions in the United States, and environmental compatibility. Since EPA's program will exist for only a few years, it is recommended that programs be funded primarily in the categories that will prove most effective in the short-run. However, ranking for combination of three methods does not apply in any way to combinations of two methods given above.

Table 1. Summary of status of combinations available for integrated weed control using two methods.

	Chemicals	Pathogens	Insects	Hybrid carp	Grass carp	Mechanical	Drawdown
Chemicals	-	B	B	B	A	A	A
Pathogens	-	-	A	C	C	C	C
Insects	-	-	-	C	C	C	C
Hybrid carp	-	-	-	-	-	C	C
Grass carp	-	-	-	-	-	B	A
Mechanical	-	-	-	-	-	-	A
Drawdown	-	-	-	-	-	-	-

A - Now available or available within the next year.

B - In testing phase but requires more research.

C - Methods for these combinations should be developed.

Table 2. Ranking, in relative rapidity of development, of combinations of methods that can be used for integrated control of aquatic weeds.

Overall Rank	Method	Availability of data	Environmental Compatibility	Plant type	Region
1	Chemical + Mechanical (drawdown)	1	2	submerged 1 emergent 2 algae 2	SE 1 NE 1 MW 1 West 1
2	Chemical + Mechanical + Fishes	1	1	submerged 1 emergent 1 algae 2	SE 1 NE 4 MW 2 West 2
3	Fishes + Mechanical (drawdown)	1	2	submerged 1 emergent 2 algae 2	SE 1 NE 4 MW 2 West 2
4	Chemical + Mechanical + Competitive plants	3	1	submerged 3 emergent 3 algae 4	SE 3 NE 3 MW 3 West 2
5	Chemical + Insects + Pathogens	4	2	submerged 3 emergent 2 algae 4	SE 3 NE 4 MW 4 West 4

PARTICIPANTS

WORKSHOP ON AQUATIC WEEDS: CONTROL AND ITS ENVIRONMENTAL CONSEQUENCES

CHEMICAL CONTROL GROUP

A. Leon Bates (Chairman)
Tennessee Valley Authority
Water Quality and Ecology Branch
Muscle Shoals, AL 35660

Kerry Steward
U.S. Department of Agriculture
Aquatic Plant Management Laboratory
3205 S.W. 70th Avenue
Ft. Lauderdale, FL 33314

Frank Harris
Wright State University
Department of Chemistry
Dayton, OH 45435

Howard Westerdahl
U.S. Army Corps of Engineers
Waterways Experimental Station
P.O. Box 631
Vicksburg, MS 39180

MECHANICAL CONTROL GROUP

James McGehee (Chairman)
U.S. Army Corps of Engineers
Operations Division (SAJOD-OR)
P.O. Box 4970
Jacksonville, FL 32201

Wade West
U.S. Army Corps of Engineers
Waterways Experimental Station
P.O. Box 631
Vicksburg, MS 39180

Louis Decell
U.S. Army Crops of Engineers
Waterways Experimental Station
P.O. Box 631
Vicksburg, MS 39180

Michael Perkins
Department of Civil Engineering
University of Washington
Seattle, WA 98195

PARTICIPANTS (Con't)

BIOLOGICAL CONTROL GROUP

Woody Miley (Chairman)
State of Florida
Department of Natural Resources
202 Blount St.
Tallahassee, FL 32301

Ted Center
U.S. Department of Agriculture
Aquatic Plant Management Laboratory
3205 S.W. 70th Avenue
Ft. Lauderdale, FL 33314

T.E. Freeman
University of Florida
Institute of Food and Agricultural Sciences
Plant Pathology Department
Gainesville, FL 32611

Rue Hestand
Florida Game and Freshwater Fish Commission
P.O. Box 1903
Eustis, FL 32726

Steven Smith
Florida Game and Freshwater Fish Commission
600 S. Maridian
Tallahassee, FL 32301

Wilber Mauck
U.S. Department of the Interior
Fish and Wildlife Service
Columbia National Fisheries Research Laboratory
Route 1
Columbia, MO 65201

Thomas Bott
Stroud Water Research Center
Academy of Natural Sciences of Philadelphia
R.D. 1, Box 512
Avondale, PA 19311

INTEGRATED CONTROL GROUP

Jerome Shireman (Chairman)
University of Florida
Institute of Food and Agricultural Sciences
Gainesville, FL 32611

William Haller
University of Florida
Institute of Food and Agricultural Sciences
Gainesville, FL 32611

Thomas Jackson
U.S. Department of the Interior
CNFRL Field Research Laboratory
Box 25007
Denver Federal Center, Code 1522B
Denver, CO 80225

Robert Gorden
Illinois Institute of Natural Resources
State Natural History Survey Division
172 Natural Resources Building
Urbana, IL 61801

Darwin Wright
Environmental Protection Agency
Agriculture and Non-Point Source Management Division
401 M St., SW
Washington, DC 20460

AGENDA

WORKSHOP ON AQUATIC WEEDS: CONTROL AND ITS ENVIRONMENTAL CONSEQUENCES

Monday, February 25

8:30 a.m. Opening remarks: Henry F. Enos, Director Environmental Research Laboratory, Gulf Breeze.

9:00 a.m. Open discussion: Chemical Control Leader: A. Leon Bates.

10:30 a.m. Break.

10:45 a.m. Open discussion: Biological Control Leader: Woody Miley.

12:15 a.m. Lunch.

1:15 p.m. Open discussion: Mechanical Control Leader: James McGehee.

2:45 p.m. Break.

3:00 p.m. Open discussion: Intregrated Control Leader: Jerome Shireman.

Tuesday, February 26

8:30 a.m. Control groups meet to prepare advisory reports.

12:00 noon Lunch.

1:00 p.m. Tour of laboratory (optional).

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